OCEAN ACOUSTICS TURBULENCE STUDY

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LONG-TERM GOALS

Use high frequency broadband acoustic scatter to quantitatively measure the one-component three-dimensional wavenumber spectrum of ocean scalar and vector turbulence.

OBJECTIVES

High frequency acoustic signals scattered from medium variability can be used to invert for the sound speed or density variability of the scattering volume. High frequency broadband acoustics are well suited for studying volume variability on the mm to cm, and msec, spatial and temporal scales.

The governing equation of motion is developed by considering the behavior of a sound wave as it travels through a homogeneous region and encounters a localized anomalous region. This is expressed as the inhomogeneous Helmholtz equation with the source term representing the scattering due to the anomalous region. For fluid variability, the source term can be simply and compactly expressed as the sum of the relative compressibility, density, and fluid velocity. For scattering from a thermally generated turbulent field, the sound speed variability due to changes in compressibility is the dominant scattering mechanism. The scattering form factor is determined by solving the integral form of the Helmholtz equation. When the index of refraction fluctuations due to the anomalous scattering region are small, the single scattering approximation is satisfied and the unknown pressure field in the anomalous region is replaced with the incident field. Additionally, when the far-field condition is satisfied the Bragg scattering condition reduces the integral equation to a one-component three-dimensional fourier transform of the variability of the scattering field. Under these conditions the acoustic scatter yields a quantitative result which can be directly compared to insitu measurements.

The accuracy of the acoustic estimation of the sound speed, density, or fluid velocity fluctuations can be determined by comparing the acoustic estimates to independent measurements of the volume variability. This requires that: 1) the scattering volume remains frozen in space and time long enough to allow independent measurements to be made, and 2) that similar spatial and temporal scales exist are sensed by the acoustics and the environmental measurements. At present, the desired environmental measurements are difficult due to limitations in available sensor sensitivities. In addition, understanding *in situ* measurements of ocean turbulence using high frequency acoustics are complicated by the presence of particulates and biology which can produce scatter of similar magnitude to that of turbulence. Finally, the theoretical assumptions used to describe the acoustic scatter, namely far-field weak scattering theory, are often not satisfied, further complicating proper interpretation of the acoustic scatter.

The research performed by Dr. John Oeschger during his one year tenure at NRL addressed the following issue:

1. Verification of the prediction made by the far-field Bragg scattering condition. The Bragg condition predicts that multi-static broadband acoustic systems can be used to more fully resolve the wavenumber spectrum of the scattering field by patching together spectral information from various bistatic geometries.

APPROACH

A controlled set of laboratory experiments were designed to investigate some of the assumptions underlying the scattering theory. It is noteworthy that one of the beginning assumptions of the theory, namely the far-field approximation is usually well satisfied when the length scale of the scatterer is less than the Fresnel radius. However when the scattering field is distributed throughout the scattering volume over many Fresnel radii, which is often the case for a turbulent field, this scattering occurs in near-field conditions. The far-field condition allows one to extract the wavenumber spectrum of the scattering field. It also results in an indirect means, through the Bragg condition, to test the internal consistency of the acoustic scatter, the next best thing to making independent environmental measurements of the scattering volume. The Bragg scattering condition states that measurements made at neighboring scattering angles yet at the same Bragg wavenumber have identical spectral estimates. The far-field scattering condition can be tested by comparing overlapping segments of the estimated wavenumber spectrum made from multi-static measurements. They should be the same if the theory is correct. One simple way to satisfy this requirement is to limit the source to volume and volume to receiver ranges such that the volume is in the far-field of the tranducers, but not so far that the ratio of the of the radius of the beam pattern at the volume, rb, to the Fresnel radius, rf, is less than or equal to one. This so called “middle-field” simulates an ideal far-field condition. This temporary limitation can be lifted in the future by using narrower acoustic beams, keeping the ratio of rb/rf less than or equal to one valid for greater ranges.

WORK COMPLETED

The experiments performed used three-channel, multi-static, short duration broadband transmit pulses scattering from a thermally generated buoyant plume. This scattering is well described using first order perturbation theory in sound speed. The range of frequencies used were between 250 and 750 kHz, the system repetition rate was 67 Hz. Time series measurements of the acoustic scatter were made for various three-channel combinations of scattering angles, from near forward angles to near backscatter.

RESULTS

Overlapping wavenumber spectrum, for far field scattering conditions, between data collected at nearby scattering angles must be equal in magnitude for identical wavenumbers. Repeated time series measurements show the overlapping wavenumber spectrum comparisons being in agreement. A typical spectrum wavenumber comparison is illustrated in Fig. 1 for the case of a three-channel, 80, 120 and 160 degree scattering angle measurement from a turbulent plume. Notice the spectrum is nearly identical in regions with overlapping wavenumbers. Also noteworthy are the presence of nulls in the wavenumber spectrum of the scattering field, these being similar in appearance at any one instance to scattering from particulates or biology, yet are the result of scattering from a turbulent temperature field. However a mean of the time series measurements show the nulls tend to average out, leaving a smoothed wavenumber spectrum, as shown in Fig. 2.

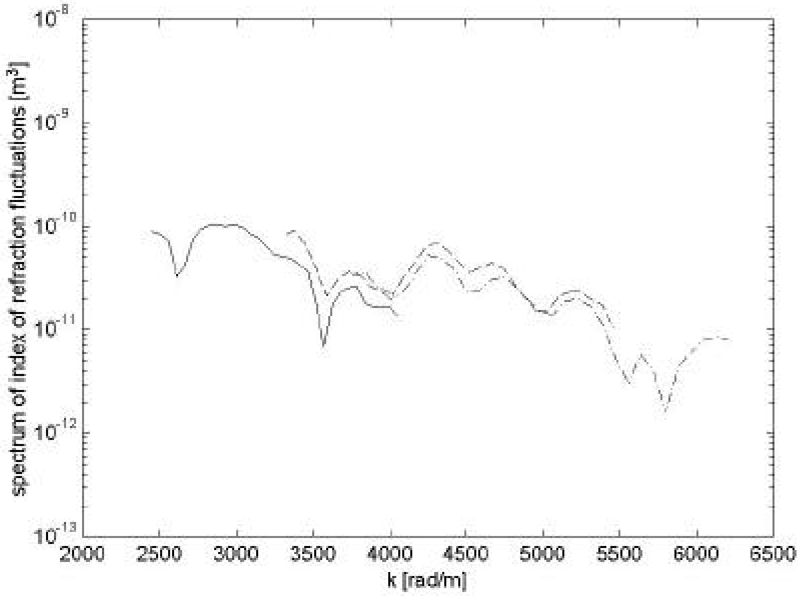

Figure 1. Overlapping wavenumber spectrum of index of refraction fluctuations for data collected at 80(-), 120(--), and 160(-.) degree scattering angles.

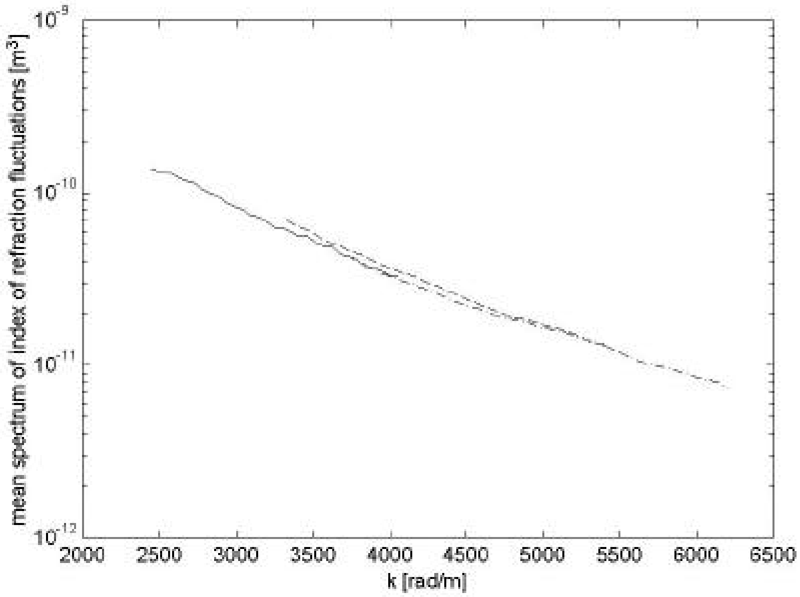

Figure 2. Mean overlapping wavenumber spectrum of index of refraction fluctuations for data collected at 80(-), 120(--), and 160(-.) degree scattering angles.

IMPACT/APPLICATIONS

When the far-field condition is satisfied with the additional requirement of rb/rf<=1, the acoustic signal yields a one-component three-dimensional Fourier Transform of the turbulent temperature wavenumber spectrum. The validity of the acoustic results can be inferred by the spectrum wavenumber comparisons. These results indicate that high frequency acoustic scatter can be used to measure remotely and quantitatively medium variability at spatial and temporal scales that are difficult to achieve with presently available insitu sensors.

TRANSITIONS: None yet

RELATED PROJECTS:

REFERENCES:

J. Oeschger and L. Goodman, "Acoustic scattering from a thermally driven buoyant plume," J. Acoust. Soc. Am. **100**, 1451-1462 (1996)